CALORIFIC VALUES OF *MISCANTHUS* X *GIGANTEUS* BIOMASS CULTIVATED UNDER SUBOPTIMAL CONDITIONS IN MARGINAL SOILS

Diana NEBESKÁ, Josef TRÖGL, Dominika ŽOFKOVÁ, Alena VOSLAŘOVÁ, Jiří ŠTOJDL, Valentina PIDLISNYUK

Jan Evangelista Purkyně University in Ústí nad Labem, Faculty of Environment, Králova výšina 3132/7, Ústí nad Labem, 400 96, Czech Republic, josef.trogl@ujep.cz

Abstract

Miscanthus x giganteus is a second-generation biofuel crop with C4-photosynthesis, efficient water usage and high resilience to environmental conditions. From sustainability point of view is promising its cultivation on marginal soils, such as brownfields or contaminated sites. These soils however provide suboptimal cultivation conditions which can affect the quality of biomass including calorific values. In this work we have determined calorific values of young *M. x giganteus* biomass samples (1 or 2 years of cultivation) cultivated in various marginal soils. Obtained average calorific value was 17.44±0.70 MJ/kg (dry mass), which is value comparable to firewood or middle quality brown coal. The variability of calorific values was quite large. Stems had slightly but significantly higher calorific values compared to leaves. Significantly higher calorific values were also obtained for field experiments than for pot experiments. Plant growth regulator (PGR) Stimpo increased significantly stems calorific value compared to non-treated plants while the calorific values of plants treated by PGR Charkor were comparable with non-treated control. Cultivation of *M. x giganteus* in petroleum industry contaminated soil resulted in the most significant reduction of calorific values of leaves besides order of magnitude reduction of quantity of biomass. Overall the results show that from energetic point of view, *M. x giganteus* provides highly energetic biomass even if cultivated in marginal soils and it is thus promising for sustainable use of such localities.

Key words: *Miscanthus x giganteus; calorific values; energetic biomass; phytomanagement; brownfields*

Introduction

Second generation biofuel crop *Miscanthus x giganteus* is considered to be one of the most perspective alternative feedstocks for energy production. Thanks to C4-photosynthesis, efficient water usage and high resilience to environmental conditions it is a good candidate for cultivation in marginal sites with suboptimal soil conditions (low availability of nutrients, water retention capacity, contamination, etc.). Simultaneously with biomass production it provides series of environmental benefits helping to improve soil quality and restore disturbed ecosystem functions (Lewandowski et al. 2000; Pidlisnyuk et al. 2014; Nsanganwimana et al. 2014). Idea of miscanthus cultivation in abandoned land is already far from just fundamental laboratory research. *M. x giganteus* biomass production in marginal sites in industrial scale and its processing into various biobased products is currently carried out for example in Great Britain under leadership of Terravesta company with satisfactory yields (https://www.terravesta.com). Anyway various suboptimal conditions of marginal soils can affect biomass production (Wanat et al. 2013; Nebeská et al. 2019; Andrejić et al. 2019). For that reason significant effort is invested in research of amendments with potential of improving soil quality (Teat

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et al. 2015; Pogrzeba et al. 2018; Kharytonov et al. 2019) or in direct promotion of plant growth using plant growth regulators (PGRs) (Ponomarenko et al. 2010; Nebeská et al. 2019).

Although novel value chains using miscanthus biomass as a feedstock are under development (for example within international GRACE project, https://www.grace-bbi.eu), direct combustion is still one of the most favourable applications (Daraban et al. 2015). It is known from previous research (Baxter et al. 2014; Bilandzija et al. 2017) that soil properties can significantly affect biomass quality. Calorific value is one the most important parameters of biomass intended for use as fuel. It can be determined as higher heating value (HHV) which is the amount of heat released during fuel combustion when all products are turned back to pre-combustion state (25 °C), so the heat of water condensation is included in value. Lower heating value (LHV) is calculated by subtracting the heat of water vaporization from HHV (Mericboyu et al. 1998).

In this study we gathered calorific values of samples of *M. x giganteus* biomass grown in various marginal soils and subjected those to statistical comparisons. The aim was to verify suitability of this biomass as fuel for heat production and identification of factors which can affect it.

Materials and methods

M. x giganteus biomass for this study was obtained from two different experiments of several variants. Complex results of these experiments will be presented later. Briefly the first one was realized in pots in laboratory conditions with contaminated soil, the second one was realized in fields with lower quality soil.

Pot experiment in 20 L containers lasted two seasons and it was established with three different real contaminated soils: agricultural soil (Cd contamination), post-military soil from former military airport (Cd, Pb, Zn contamination) and mixture of post military soil with highly petroleum contaminated soil from refinery sludge lagoon (hydrocarbons, Cd, Pb, Zn, Cu contamination).

Field experiment was established during two years in four localities: two different sites in the area of former military airport with very poor sand soil (two years of cultivation), research field of Crop research institute with lower quality agricultural soil (partly one and two years of cultivation) and site located in the area of landfill which was built above abandoned brown coal mine (one year of cultivation). Part of *M. x giganteus* rhizomes in this experiment was treated with commercially available PGRs Stimpo and Charkor which were provided by Agrobiotech, Ukraine (http://www.agrobiotech.com.ua). Used PGRs are listed in Table 1. The treatment was done by soaking rhizomes in PGR solution for 12 hours before planting. Control plants were soaked in distilled water for the same time.

Table 1. PGRs used for field experiment and year of cultivation when sampling was realized

Site	PGR	Year of cultivation
Post-military airport 1	Stimpo 1 mL/L	2
Post-military airport 2	Stimpo 1 mL/L	2
Agricultural 1	Stimpo 2.5 mL/L	2
Agricultural 2	Charkor 4 mL/L	1
Landfill	Stimpo 1 mL/L, Charkor 4 mL/L	1

Biomass was sampled in November when it turned yellow and dry. Leaves and stems were separated, cut into pieces 2 – 3 cm long and dried in the oven at 105 °C to constant mass. Higher heating value (HHV) of dry biomass was determined according to ČSN ISO 1928 (441352) (ISO 2010) with oxygen bomb calorimeter (Ilabo, IKA C 5000 control).

Evaluation of the data was carried out using Microsoft Excel and Statistica software pack version 13.3. Significance of differences between groups was tested using two sample t-test and 95% confidence interval.

Results and discussion

Detailed statistical characteristics of the dataset are presented in Table 2. The mean HHV value of all results was 17.44 ± 0.70 MJ/kg. That is little lower than values reported for miscanthus biomass grown in regular soil (Table 3) but still comparable for example with middle quality brown coal, some types of wood or wheat straw (Table 4). So even if *M. x giganteus* is grown in lower quality marginal soils, it can provide biomass with sufficient calorific value to be used as a fuel.

Table 2. Overall statistical characteristics of used dataset

Parameter	Value
Number of values (n)	71
Average	17.44
Std. deviation	0.70
95% confidence	17.27-17.60
Median	17.52
Lower quartile	17.27
Upper quartile	17.77
Min. value	14.07
Max. value	18.82

Table 3. Miscanthus HHV (dry basis) in previous field studies with regular soil

Country	Harvest time	HHV (MJ/kg)	Reference
United Kingdom	October	17.54±0.13 (n=4)[a]	Jensen et al. 2017
United Kingdom	February	17.58±0.05 (n=4)[a]	Jensen et al. 2017
Germany	March	17.74	Michel et al. 2006
France	-	17.8[b]	Jeguirim et al. 2010
Spain	-	18.07±0.16[b]	García et al. 2012
Croatia	autumn + winter + spring	18.19±0.27 (n=108)[b]	Bilandzija et al. 2017
United Kingdom	September	18.2[a]	Mos et al. 2013
United Kingdom	February	18.8[a]	Mos et al. 2013
Poland	July	19.04[b]	Dukiewicz et al. 2014
United Kingdom	February	19.19±0.30 (n=6)[a]	Baxter et al. 2014

[a] calculation from ultimate analysis; [b] calorimetry

Table 4. The HHV (dry basis) of selected solid fuels, adopted from Parikh et al. (2005)

Fuel	HHV (MJ/kg)
Coal (black coal)	32.86 – 33.00
Lignite (brown coal)	15.63 – 25.10
Wood chips	19.91
Softwood	20.00
Pine wood	16.64
Wheat straw	17.00 – 18.91

Anyway, considering previously reported values, the variance of HHV in our study was quite high (14.07 – 18.82 MJ/kg). Thus, we investigated the effect of selected factors which could influence the results.

The plant part (stems vs. leaves) was one of the significant factors (Figure 1a). It was tested only for pot experiment as in the field only stems were collected. In accordance with study of Baxter et al. (2014) we found that stems (17.32±0.30 MJ/kg) provided significantly higher calorific value compared to leaves (16.82±0.81 MJ/kg). This result is consistent with the fact that miscanthus stems are more lignified compared to leaves, since lignin is the most heating component of biomass (Schäfer et al. 2019).

Another factor which significantly affected calorific value was the method of cultivation (pot vs. field, Figure 1b). This factor was tested only for stems. Stems collected in the field experiment (17.87±0.30 MJ/kg) had significantly higher HHV compared to those cultivated in pots (17.32±0.30 MJ/kg). Similarly different results of phytoremediation in pot and field study were described by Pelfrêne et al. (2015) and higher metal-induced stress of pot-cultivated *M. x giganteus* compared to field was already reported (Al Souki 2017). Nevertheless, these differences might be also caused by used soils and their properties since there was no soil presented in both groups and by different climatic conditions during cultivation.

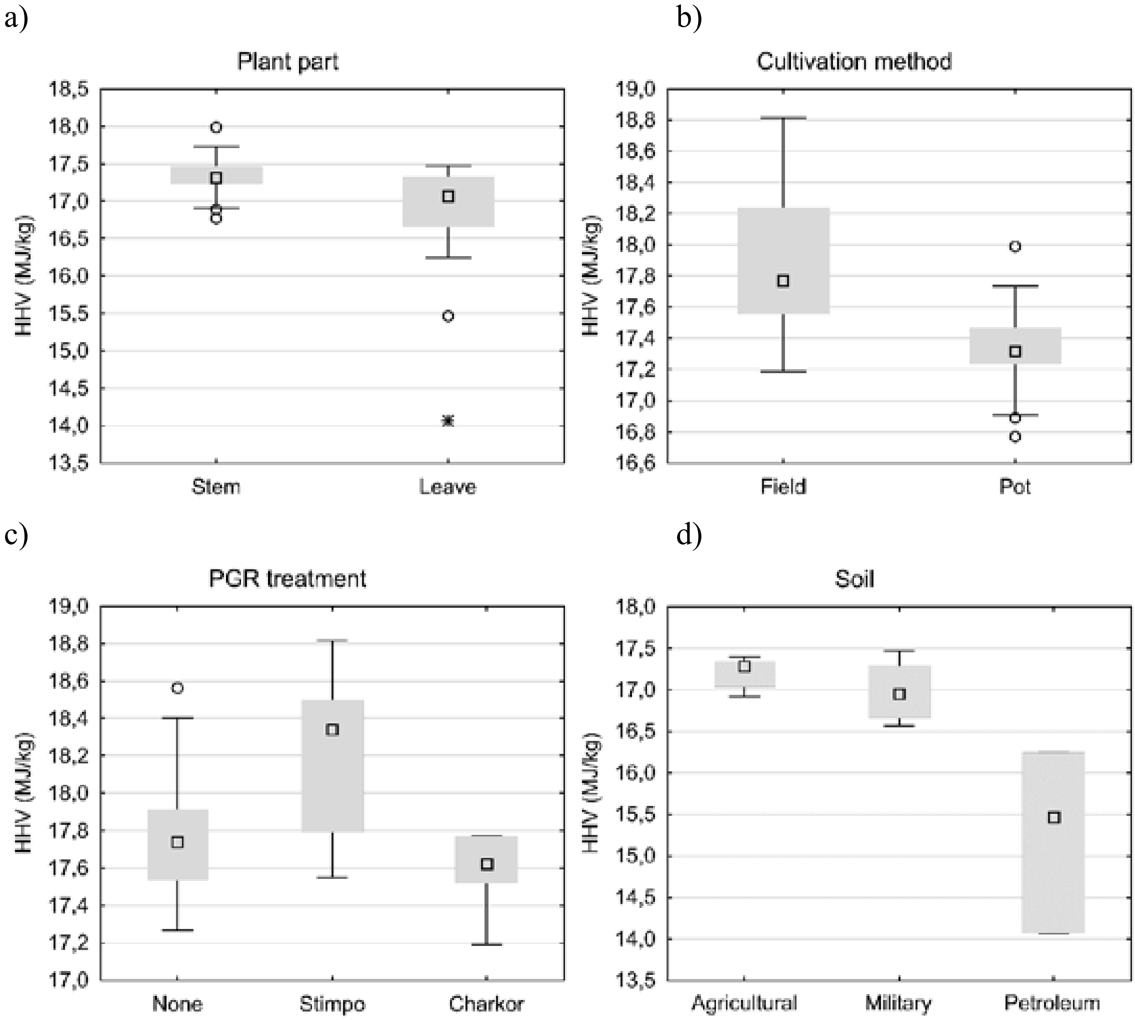

Figure 1. Boxplots of effect of **a)** plant part, **b)** cultivation method, **c)** PGR treatment and **d)** soil contamination on calorific value (square: median, circle: outlier, asterisk: extreme)

PGR treatment was tested only in the field experiment and revealed differences between the effect of Stimpo and Charkor (Figure 1c). While Stimpo application significantly increased stems calorific value (18.21±0.45 MJ/kg) compared to non-treated plants (17.80±0.35 MJ/kg), Charkor treated plants calorific values (17.58±0.22 MJ/kg) were comparable with non-treated control.

The last significant factor identified was soil quality (Figure 1d). It was only tested for pot experiment leave samples as we were not able to collect sufficient stem samples repetitions due to highly limited stems production in petroleum variant. While in agricultural and military soils (both together) HHV was 16.93±0.77 MJ/kg, in petroleum soil it was only 15.26±1.10 MJ/kg.

On the other hand, the year of harvesting (only stems tested) did not have significant effect on HHV results.

The results generally confirm that *M. x giganteus* biomass has high heating value even if it is cultivated in suboptimal conditions. Considering previously reported results, the HHV exhibited quite high variability and we have detected significant differences in several cases. The lowest values were determined in case of *M. x giganteus* cultivation in petroleum industry contaminated soil. Even this biomass could be used as a fuel, however the absolute obtained biomass quantity was order of magnitude lower compared to other soils. Unless the tolerable concentration of petroleum and especially synergy with other factors are better understood we can not recommend using *M. x giganteus* generally for phytomanagement of petroleum industry contaminated soils.

Two PGRs (Stimpo and Charkor) were previously tested on energy crops including *M. x giganteus* in an attempt to improve the biomass parameters with ambiguous results (Ponomarenko et al. 2010; Nebeská et al. 2019). Our experiment revealed slightly positive effect of Stimpo on the calorific values. The mechanism of this increase shall be investigated in further research.

Generally, the collected data represent quite heterogenic group of variants. We used several soils, different contaminations, field vers. pot experiments etc. This enables a variety of data mining, however obtained results should be considered only as hypotheses due to possible unearned factors or multicorrelation between values. Further more detailed experiments shall be carried out to verify them.

Conclusions

Calorific values of *Miscanthus x giganteus* biomass cultivated in various contaminated or marginal soils ranged between 14.07 and 18.82 MJ/kg. The lowest values were detected for petroleum industry contaminated soil besides order of magnitude reduction of biomass. On the other hand, the highest values were obtained after application of plant growth regulator Stimpo and for plants cultivated in field compared to pots. Further research is needed to confirm the differences and reveal their mechanism. Regardless the overall calorific values were high enough to enable energetic use of the biomass.

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